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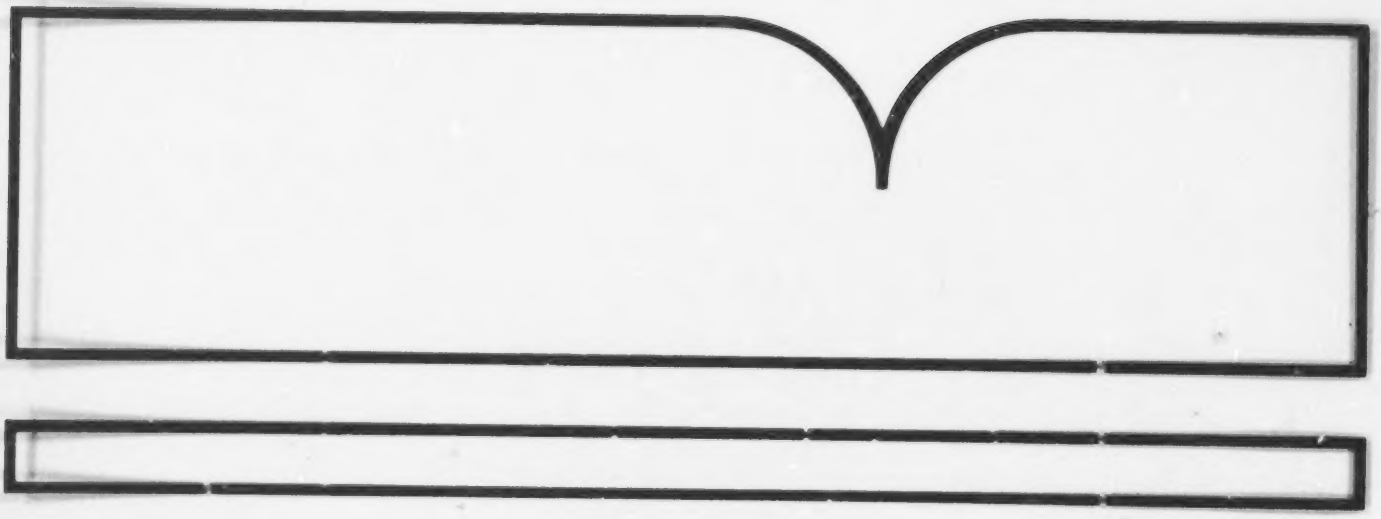
EPA's (Environmental Protection Agency's) Risk Assessment Methodology for Municipal Incinerator Emissions: Key Findings and Conclusions Report of the Municipal Waste Combustion Subcommittee Environmental Effects, Transport and Fate Committee

(U.S.) Environmental Protection Agency
Washington, DC

Prepared for

Apr 87



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The subcommittee considered the proposed methodology to be a considerable improvement over other multi-media risk assessment methodologies previously developed by EPA and reviewed by the Science Advisory Board. The current methodology was more comprehensive in scope and, in general, provides a conceptual framework that ought to be expanded to other environmental problems.

The Subcommittee identified several areas in this methodology that need further consideration, including: the applicability of the Hampton incinerator facility and associated data to represent typical mass burn technology; the failure to use data from current best available control technology facilities for model validation; separate treatment of particulate and gaseous emissions and their fate, i.e., downwash; the need to use best available kinetics in predicting soil degradation; exposure resulting from the landfilling of ash; using the maximally exposed individual (MEI) concept; and the treatment of plant (and herbivore) exposure.

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

April 9, 1987

OFFICE OF
THE ADMINISTRATOR

The Honorable Lee M. Thomas
Administrator
U.S. Environmental Protection Agency
401 M. Street, S.W.
Washington, D.C. 20460

Dear Mr. Thomas:

The Science Advisory Board's Municipal Waste Combustion Subcommittee has completed its review of a document jointly prepared by the Office of Air Quality Planning and Standards and the Environmental Criteria and Assessment Office entitled Methodology for the Assessment of Health Risks Associated with Multiple Pathway Exposure to Municipal Waste Combustor Emissions, as requested in the Subcommittee's charge. The review was requested by both offices and was conducted on November 10, 1986 in Research Triangle Park, N.C.

The Subcommittee considered the proposed methodology to be a considerable improvement over other multi-media risk assessment methodologies previously developed by EPA and reviewed by the Science Advisory Board. The current methodology was more comprehensive in scope and, in general, provides a conceptual framework that ought to be expanded to other environmental problems.

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The Subcommittee's review of this methodology is part of its larger evaluation of the scientific knowledge and uncertainties related to municipal waste combustion. Because of EPA's need to meet a court deadline, the Subcommittee is issuing this methodology review as a separate report. It also plans to assess the Office of Research and Development's municipal waste combustion research strategy.

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The Subcommittee appreciates the opportunity to conduct this scientific review. We request that the Agency formally respond to the scientific advice transmitted in the attached report.

Sincerely,

Rolf Hartung, Chairman
Municipal Waste Combustion Subcommittee
Science Advisory Board

Norton Nelson, Chairman
Executive Committee
Science Advisory Board

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SAB-EETFC-87-027

EPA'S RISK ASSESSMENT METHODOLOGY FOR MUNICIPAL INCINERATOR EMISSIONS: Key Findings and Conclusions

REPORT OF THE MUNICIPAL WASTE COMBUSTION SUBCOMMITTEE
Environmental Effects, Transport and Fate Committee

SCIENCE ADVISORY BOARD
U.S. ENVIRONMENTAL PROTECTION AGENCY
Washington, D.C.

April 1987

U. S. ENVIRONMENTAL PROTECTION AGENCY

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ASSESSING EPA'S RISK ASSESSMENT METHODOLOGY FOR MUNICIPAL INCINERATOR EMISSIONS: Key Findings and Conclusions

Introduction

On November 10, 1986, the Municipal Waste Combustion Subcommittee of the Environmental Effects, Transport and Fate Committee of EPA's Science Advisory Board reviewed a draft document entitled "Methodology for the Assessment of Health Risks Associated with Multiple Pathway Exposure to Municipal Waste Combustor Emissions" prepared by the Office of Air Quality Planning and Standards (OAQPS) and the Environmental Criteria and Assessment Office (ECAO). This document will be referred to hereafter as the "methodology".

The purpose of the risk assessment and exposure methodology developed in the document under review is to examine the potential health and environmental effects exposed populations are likely to experience as a result of municipal waste combustion (MWC) technologies. This asessment allows comparison of variations in the efficiency of combustor design and operation, and is also intended to predict the effects resulting from multiple exposures to emissions from more than one source.

OAQPS and ECAO requested the Subcommittee to evaluate the scientific validity of the methodology for assessing health risks associated with multiple pathway exposures to municipal waste combustor emissions. Specifically, the Subcommittee was asked to determine whether the methodology provides a reasonable scientific approach to evaluating effects on public health given the available data, the validity of exposure assessments, and the appropriateness of transport and dispersion models. The Subcommittee's key findings are reported in the following pages; detailed comments and meeting transcripts have been provided to appropriate Agency authors.

General Comments and Methodology Overview

Overall, the Subcommittee considers the proposed methodology to be conceptually thorough, although it identifies a number of areas where specific technical improvements are needed. Since the methodology will be used as a technical support document for regulatory decision making, a thorough technical effort is necessary. The approach also makes reasonably effective use of existing scientific data and exhibits the degree of accuracy and understanding needed for using models. The Subcommittee consensus is that the methodology is a credible effort towards developing a tool for assessing multiple media exposures from this source category.

The Subcommittee commends the authors on both the tone and the detail used in documenting the assumptions that support the methodology. The uncertainties and possible consequences of

using the methodology are clearly presented in a number of instances, such as limitations created by focusing on stack pollutants rather than total pollutant loadings (e.g., ash residues, aqueous residues, and stack emissions). Another concern is the uncertainty in identifying specific pollutants in emissions from a municipal waste combustor, since characterizing emissions improves the ability to predict the physical and chemical properties and effects of emitted substances. The authors are clearly aware that the methodology they have developed is but a step in a development process to expand current risk assessment methodologies to include other pathways, in addition to atmospheric, exposures beyond inhalation and non-human effects.

The Subcommittee has several recommendations for placing the scientific issued raised by the use of this technology into better perspective. These recommendations include:

° The methodology should attempt to predict the risk posed from both combustion as a whole and from specific activities, such as automobile use, industrial practices (e.g., coal combustion for energy production), and both hazardous chemical and municipal incineration.

° While individual scenarios are modeled in this methodology, calculating dose from the source and dispersal through various pathways does not lead the reader to understand the entire risk perspective that incineration technologies present.

° In applying the models, the methodology utilizes two separate sites as examples: 1) Hampton, Virginia, and 2) a proposed, or hypothetical, state-of-the-art facility to be located in Florida. Although both sites are individually discussed and evaluated as to the risks they presumably pose, they are not compared. Since risk assessment is a comparative tool, the Subcommittee recommends that the chosen sites be evaluated in comparison to one another, and for reasons to be discussed later, recommends that facilities in addition to Hampton be used for this comparison.

° The subcommittee believes that the most appropriate data for monitoring MWCs may be derived from combining actual field measurements with predictions from mathematical models. For the field measurements, this presupposes that measurements have been made in appropriate locations, at appropriate times, and with appropriate methods. It also presupposes, for the mathematical models, that they have been validated at least to the extent that their limitations are understood and that the range of divergence between model predications and reality can be quantified. In this context it is important to consider both statistical variability and its propagation through the model, as well as conceptual biases which inherently result from making the

simplifying assumptions required for the construction of models. The Subcommittee recognizes that elements of this recommendation are best carried out through a longer-term research program.

The document should definitely state that, even when models are validated, actual data are preferable to results predicted by models. Also, the methodology should caution that the existence of a useful model should not substitute for or discourage the collection of site specific data. In addition, the methodology should encourage the use of field data and model application in concert.

The methodology appropriately states that much of the information needed to further support its development does not exist, and that some assumptions about non-existent data must be made to make initial predictions. However, the specific choices in such assumptions raise several questions for the Subcommitte, which are addressed in the sections to follow.

The Subcommittee recommends that uncertainties be identified as to whether they are the result of limitations in the understanding of the MWC process itself, or a result of the predictive capability of the model.

Technology and Emissions

The document cover attempts to represent a broad perspective of exposure patterns. However, the Subcommittee is concerned that the drawing depicts a worst-case exposure scenario without illustrating the problem-solving aspects of the technology. This concern centers around the negative impression that may result from the depiction of a particulate emissions plume. It was also noted that the illustration represents a rural setting, and does not depict the urban environment, where most incinerators may be built.

The methodology reviews the state-of-the-art for existing and projected municipal waste combustors, and provides useful background information. However, various sections on existing and projected facility sites are inconsistent with regard to future locations. In addition, projections for California may be misrepresented. The Subcommittee believes that it is important to distinguish between the number of facilities and the number of incinerator furnaces, since most facilities consist of several incinerators that can be operated independently.

Using a combination of dry scrubber and fabric filter technology for pollution control is reported to reduce mercury emissions by 50 percent. Data actually demonstrate that at 140 degrees Celsius (C) or below, 95-97 percent collection is achieved, while at 209 degrees C, no collection is achieved. The average may be 50 percent, but averaging this type of data does not accurately represent the performance of the control system.

The methodology discusses many factors that may influence emissions. The apparent and ultimate conclusion is that the efficiency of the air pollution control system determines the emission level of particulate matter (PM) and associated pollutants from the stack. This conclusion should be clearly stated.

The Subcommittee disagrees with the use of the Hampton facility to represent existing incinerators and their emissions. Use of this inappropriate example will yield a gross overestimation of emissions from new incinerators. The Hampton data set may be extensive, but the technology used at the facility is hardly representative of typical mass burn technology. The design and operating practices used at Hampton should be explained, along with the fact that this design is not in common use. This facility provides a worst case scenario that is not representative of most recent installations. The results of modeling will be very different when best available control technology (BACT) is used. The Subcommittee recommends that EPA develop more scenarios, including one for BACT, that can be used to evaluate a more complete range of source and emission characteristics for existing and proposed MWC facilities.

The methodology cites three reasons to explain the presence of polychlorinated dibenzo-dioxins and furans (PCDDs and PCDFs, respectively) in MWC flue gases. A fourth reason should be added, since these organic compounds may be formed in the boiler during cooling, in the presence of fly ash (post-combustion formation). It should also be stated that little is known about reactions that occur between gaseous species within emission plumes.

The methodology recognizes that the available emissions data are limited in both quantity and quality. Few specific chemicals have been identified, although much of the total mass has been characterized as silicates and forms of carbon. There is reason to suspect that some of the chemical components of MWC emissions that remain to be identified may be toxic. However, these chemical components, such as polyaromatic hydrocarbons (PAHs), may be contributed by sources other than municipal incinerators, and background levels are not adequately established. Major data gaps exist with regard to chemical identity, toxic potential, and total environmental burden of MWC emissions, making the assessment of risk posed by the technology itself, and in comparison to other alternatives, difficult to predict.

Exposure Models

- Industrial Source Complex (ISC) Model

The introduction to the ISC model would be improved by a discussion of the likely uncertainties of the estimates for models of gaseous dispersion, particle dispersion, and wet and dry deposition of gases and particles. This discussion should

address uncertainties that arise both as a result of limitations in the understanding of the processes and those due to random variation in deposition and dispersal processes.

Although some of the assumptions made in parameterizing wet deposition may be rather crude (e.g., assumptions regarding the spatial distribution of precipitation), they are not likely to present a problem when annualized computations are made. However, the parameterization of dry deposition, particularly for emission of chemicals for which loss mechanisms are not understood, is not clear. The methodology seems to imply that gaseous components are not considered. This point needs to be clarified. The use of data concerning the size distribution of particles obtained from the Braintree MWC may not be representative, and the data on emission rates seem to be conservative.

The methodology for atmospheric dispersion and deposition of emissions should separately consider particulate and gaseous emissions and their fate. The contribution from chemicals in different physical and chemical states should be evaluated with respect to to direct and indirect routes of exposure. Variability in the size and solubility of particles should be considered. The biological availability of emitted materials is also affectad by the degree of sorbtion to particles that occurs. The discussion should specify the assumptions made about emission characteristics.

The effects of buildings on lateral and vertical dispersion of emissions has been considered in the methodology. However, careful consideration of downwash is also necessary. The proximity of other structures in urban areas and the potential for downwash are not treated in the methodology. Since one of the strengths of the ISC model is the ability to consider multiple sources, the document should also address the issue of the proximity of other incinerator facilities.

The methodology does not consider the exposure of people who do not reside at ground level. This factor could be significant for urban residents, and is compounded by the likely concentration of incinerators in urban settings.

- Human Exposure Model (HEM)

The HEM is used to estimate the carcinogenic risk posed to populations by inhalation of predicted ambient air concentrations of MWC emissions. The model assumes equivalency of indoor and outdoor concentrations, an assumption that the Subcommittee finds suspect for two reasons: 1) the finite length of typical infiltration rates ($\geq$ 1 hour, typically), and 2) the significance of indoor sources of certain chemicals.

The HEM estimates do not consider the short or long-term mobility of the population. It also assumes a 70-year lifetime for MWCs. In other parts of the methodology, a more realistic 30-year estimate is utilized. The assumption of continuous operation of MWC facility is also an unrealistic assumption.

Specific aspects of the locality and siting of the MWC facility need to be considered because of their significant effect on concentration and dispersal of pollutants.

The document should refer to the discussion of quantitative risk assessment modeling found in EPA's revised guidelines for cancer in order to provide the reader with a better understanding of the range of assumptions and models used in cancer risk assessment.

° Terrestrial Food Chain (TFC) Model

This model is used to predict the deposition of MWC emissions on soil and vegetation. Its pathways assess the exposure to humans, animals, soil biota and vegetation, and associated effects on the food chain. The TFC model has separate components for examining the potential for human exposure from ingesting contaminated soil and from consuming vegetation and animal tissues containing the contaminants. The potential for children to be exposed as a result of ingesting soil is also estimated. However, pathways of human exposure via consumption of herbivorous animals are not clearly explained. The assumption that herbivores are exposed only by ingesting soil or by consuming plants that have assimilated emitted materials deposited on soil neglects consideration of the component presenting the highest exposure potential. Herbivores are likely to receive the highest exposure from ingesting leaves of plants upon which particulate emissions have been deposited.

The Subcommittee questions the appropriateness of using sludge or pesticide amendment practices as surrogates for predicting fallout from MWC emissions. The burden of toxic compounds and metals that is created by applying sludges to soils should be compared to that presented by the assumption that rates of dioxin or furan emissions will equal or exceed 2.7 kg/ha over 50 km linear dimension as a result of MWC.

This model uses a hypothetical Florida MWC as an example for making predictions, but the input factors, such as rates of emissions, soil characteristics, and design and operation, are not documented. It is not clear whether the Florida MWC represents a best or worst case illustration. More exposition is needed with respect to both input and output parameters. These improvements would greatly enhance the reader's understanding of the methodology.

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° Exposure Pathways

The assumptions required for determining the maximally exposed individual (MEI) need to be considered more carefully to prevent the overconservatism which may result from combining the basic MEI concept with those resulting from the multi-exposure models. The MEI concept estimates the effect on only one hypothetical human subject; population effects and effects over generations are not determined. The MEI concept also does not consider acute exposure or exposures to other biota. These oversimplifications result in conservative estimates of human exposure. A new concept should also be developed which includes the cumulative probability of MEI exposure.

Another flaw in the methodology is the assumption of flat terrain. Urban or hilly settings may, in actuality, result in greater levels of human exposure.

The methodology does give appropriate consideration to soil type. Soils differ greatly, making the selection of a specific standard soil density and penetration depth tenuous. Compounds from MWC emissions will be deposited at different concentrations and will be found at varying depths in the soil, depending on soil type. Assumptions that toxicants will be concentrated in the upper centimeter of soil may be incorrect for some locations because of differences in soil density, moisture and composition. Some toxicants will be concentrated near the soil surface, while others may move down from the surface and be dispersed.

Degradation of chemicals in soil is often assumed to be a first-order reaction, even when data for specific chemicals indicate that the degradation rate is not first order. The best available kinetics should be used, since first order kinetics may often be inappropriate.

In the methodology, trace metal contaminants are assumed to persist indefinitely unless loss constants are available. A reasonable loss constant, which can be derived from soil pH values, should be used instead of making a blanket assumption that contaminants will persist.

Assuming that no degradation and no retardation takes place for chemicals in the plow depth layer is of concern when there is a lack of data to support this assumption. The fate of chemicals is known to be altered in plow depth layers composed of organic clays as a result of biologic activity.

° Surface/Ground Water Models

Tier one of the surface/ground water methodology assumes that all material deposited during a single year is incorporated into the water in the same year. This model does not take into account the potential for build-up over periods of more than one year, or the potential for this large amount of material to be released by a single storm event at some future time. In drier

climates (i.e., the Intermountain West and the Southwest deserts) major storms or "gully washers" can occur as seldom as once in 10 years, rendering doubtful the assumption that all toxicants adhering to particulates are flushed out in a one year period. Furthermore, in wet climates the opposite may be true, as some toxicants may not build up appreciably.

° Other Exposures Not Considered

As the authors point out, no consideration is given to exposures from landfilling ash. Similarly, consideration is not given to the potential for change in emission characteristics that may result from incinerator upsets. These data gaps are significant, but consistent with the inadequate knowledge regarding MWCs. The Subsommittee recommends that the methodology address these issues.

Estimation of Risk to Humans

The equation used to calculate the adjusted reference intake (RIA) is logical for application, since the use of the acceptable daily intake (ADI) is well established. Also, the use of excess concentration over background in the equation is an established measure of the potential for human health effects. However, the definition of total background intake (TBI) of pollutants from all existing sources needs some clarification.

Examples presented in the methodology use national averages to define the TBI, although these values may not be representative of the particular sites where risk is to be evaluated. The approach taken for risk assessment is based on the location with the minimum RfA, although people at this location may not be those with the maximum exposure to the pollutant. The Subcommittee believes that the values selected may not be valid for the particular sites being evaluated.

Defining the TBI as the sum of contributions from individual sources assumes that no interactions, such as synergism or antagonism, occur when sources are combined and individuals are exposed by multiple routes. There are many instances where this concept is not supported by the available data.

There is inconsistency in the methodology's treatment of exposure to background concentrations of different chemical substances. For some chemicals, such as cadmium, contributions from MWC emissions are added to contributions from all background sources to give total exposure. For other substances, such as benzo(a)pyrene, exposures to background concentrations are ignored and assessment is conducted in terms of additional risk posed by MWC contributions alone. The methodology should assess exposure to chemical substances in a consistent manner.

The prediction of inhalation exposure, which assumes that individuals are exposed to emissions only in gaseous form, neglects the potential for particulate absorption and particle

deposition. Pathways other than inhalation, such as dry depositon of particulate emissions and related dermal absorption, need to be considered.

The methodology postulates that some noncarcinogenic effects that exhibit thresholds occur only after nearly an entire lifetime of exposure. This assumption does not reflect the actual situation. For example, fibrotic lung diseases occur after less than a full life span of exposure, and their onset is very gradual. For many chemicals, the reported latency periods tend to be measured in terms of weeks or months, rather than years.

Relative effectiveness (RE) is used in the methodology to standardize effects of exposure by one route to the effects of exposure by another. There may not be scientific justification for this conversion factor. However, the concept is useful as long as users realize that the effect of an exposure does not relate solely to absorption efficiency, but is also related to differences in the sensitivity of absorption sites to damage, and to differences in toxicokinetics between exposure routes. The methodology should acknowledge the assumptions required for using this approach.

Consumption of fish by the general population is discussed, but the discussion does not take into account the fact that fish may come from a variety of sources with varying degrees of contamination. A similar situation exists for drinking water. Drinking water obtained from any one tap may consist of water from a local source, may contain water that originates outside of the localized delivery area, or may be a mixture of both. Alternatively, drinking water may be obtained from individual wells drawing on ground water from a large source or deep aquifer. Local contamination is not always represented in the localized supply of drinking water.

With regard to water consumption, the amount of fluid intake documented is low. It is not clear whether this amount represents total fluid intake or the intake of water alone. It is usually assumed that fluid intake for adults averages 2 liters per day. It is questionable, therefore, that females between the ages of 14 and 16 would only take in 586 ml water per day, as reported in the document.

Ecological Effects

The treatment of plant uptake as a linear function is erroneous unless no other information is available. Many toxicants, especially metal salts, are actively transported across membranes or cell walls and, therefore, cannot be described by a linear function.

The Subcommittee disagrees with the assumption that plants are exposed to contaminants mainly through uptake from soil. Greater exposure is likely to occur from foliar deposition. Estimates of deposition can be obtained from acid deposition

studies and also from studies of the nuclear energy industry, e.g., deposition of radioiodine (I^{131}).

The Subcommittee also questions the method used to average bioconcentration data for aquatic species. Even when means are calculated separately for bivalves and fin fishes, misleading interpretations can result. The bioconcentration data should be correlated with human dietary factors. For example, humans consume more oysters than mussels, and oysters may accumulate significantly more contaminants than mussels. Averaging bioconcentration factors together for oysters and mussels may create a significant source of error in calculating exposure to bioaccumulated chemicals.

The document summary mentions measurement of adverse effects on natural ecosystem vitality. The definition of ecosystem vitality is unclear, as are the endpoints to be used in measurement. Uptake from water is modeled, but few other environmental endpoints are considered. One important component not treated is the highest trophic level, predators. Predators play an important role in community regulation. There is also a need to consider the potential for concentration of materials in sediment, since sediments may serve as a source of contamination for overlying waters, and materials concentrated in sediment may be biologically available to benthic organisms and organisms dwelling in the water column. Assessments of exposure cannot be derived from water quality concentrations for benthic dwellers, since they are exposed in a totally different way.

In closing, the Subcommittee agrees that the methodology represents an appropriate step towards modeling and predicting exposure from MWC emissions. Some conceptual assumptions can be strengthened by closer examination of the complexities associated with pollutant emission to and interaction with the environment, while others must await collection of actual field data to fill in knowledge voids and elucidate environmental interactions. Finally, the methodology, over time, must be validated with actual data to evaluate and demonstrate its utility, and to guide its further development and refinement.

APPENDIX 1: Glossary

Glossary

ADI	Acceptable Daily Intake (mg/kg/day)
BACT	Best Available Control Technology
C	Celsius
HEM	Human Exposure Model
ISC	Industrial Source Complex (as in ISC model)
MEI	Maximally Exposed Individual
MWC	Municipal Waste Combustor
PAH	Polyaromatic Hydrocarbon
PCDD	Polychlorinated Dibenzo-Dioxin
PCDF	Polychlorinated Dibenzo-Furan
PM	Particulate Matter
RE	Relative Effectiveness of ingestion exposure
RIA	Adjusted Reference Intake (u/day)
TBI	Total Background Intake (mg/day)
TFC	Terrestrial Fate Complex (as in TFC model)

APPENDIX 2:
Executive Summary of Document Under Review:

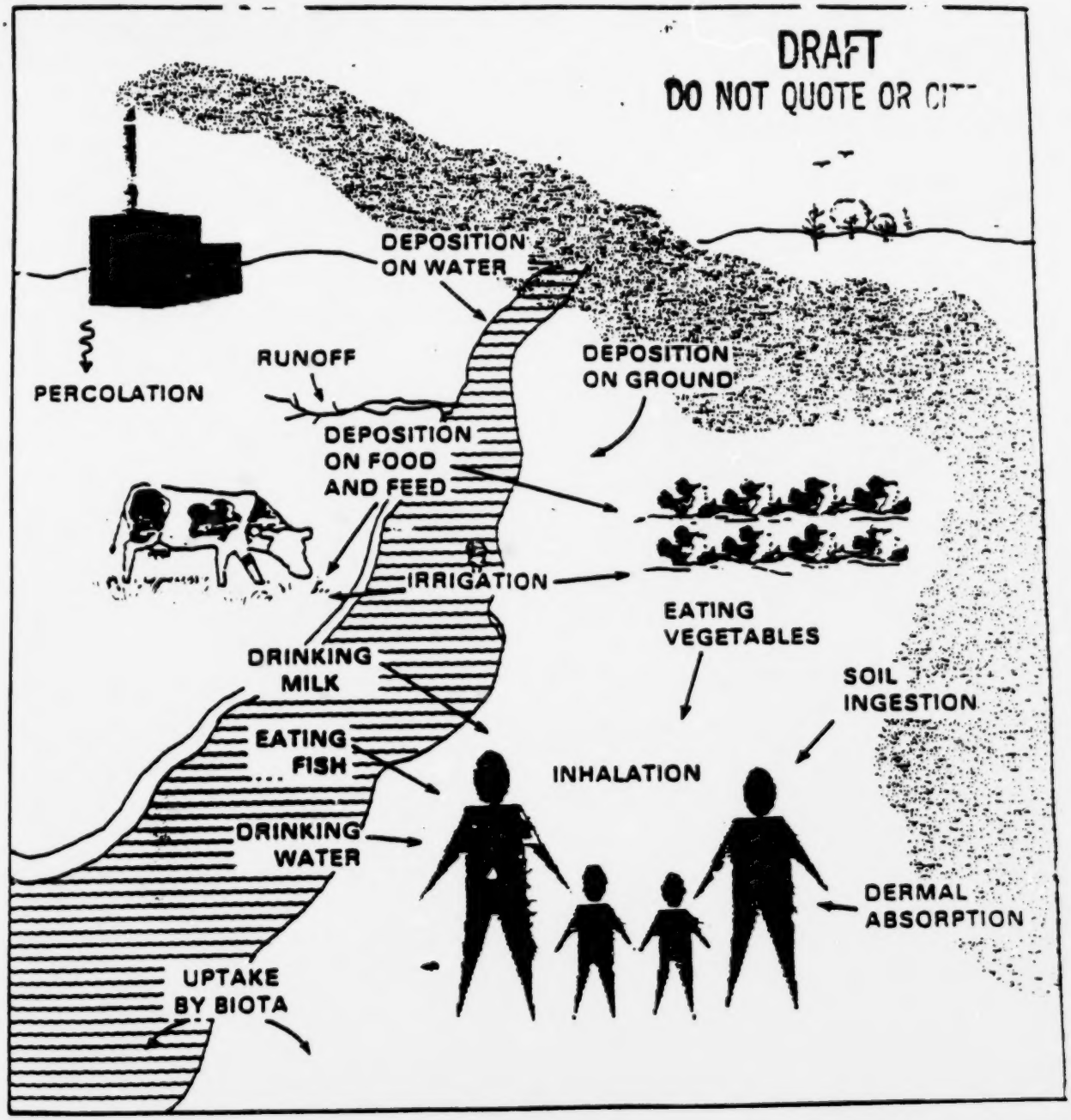
"Methodology for the Assessment of Health Risks Associated with Multiple Pathway Exposure to Municipal Waste Combustor Emissions"

EPA

United States
Environmental Protection
Agency

The Office of Air Quality Planning and Standards, RTP, North Carolina, ar
The Environmental Criteria and Assessment Office, Cincinnati, Ohio
October, 1986

Methodology for the Assessment of Health Risks Associated with Multiple Pathway Exposure to Municipal Waste Combustor Emissions



A Staff Paper Submitted for Review to the Science Advisory Boarc

EXECUTIVE SUMMARY

Each year the collective social and commercial activity in the United States produces >150 million tons of discarded waste. Commonly termed municipal solid waste (MSW), this discarded material must somehow be managed to avoid undesirable adverse consequences on human life, and the vitality of terrestrial and aquatic life.

The age-old solution to the problem of managing MSW has been to dispose of the waste in the ground in land areas dedicated to that purpose. Currently about 80% of the MSW is disposed of by land burial in ~10,000 landfills nationwide. If not properly sited, designed, and managed, these landfills can cause serious damage to the environment. For example, gases can escape the landfill and travel to residential areas potentially impacting human health, or contaminated leachate can migrate off-site into sources of potable drinking water and into sensitive natural ecosystems. Because of the possible adverse environmental impact posed by landfills, many States have imposed strict siting requirements, landfill cover requirements, leachate collection and treatment requirements, landfill gas capture and treatment requirements, and groundwater monitoring requirements to the design and operation of landfills. These requirements have significantly increased the cost of disposing MSW in landfills, and have limited land areas suitable for landfill sites.

Meanwhile the amount of MSW needing disposal continues to increase with the increase in the U.S. population. By the year 2000 U.S. society may be faced with managing the disposal of >250 million tons of MSW each year. Methods of waste management are limited by available technology. Communities can continue to only landfill MSW, or they can utilize technologies that will substantially reduce the volume of waste that is ultimately landfilled, e.g., recycling of waste and incineration of waste. While recycling strategies are being encouraged and fostered, many communities are turning to municipal waste combustion (MWCs) in order to incinerate and reduce the volume of waste by 70-90%. Current MWC technology is a distinct improvement in the design, combustion efficiency, and pollution control over combustors planned and constructed a decade ago.

They not only reduce the volume of waste, but have the added advantage of thermally recovering energy from combustion in the form of steam or hotwater that can be used in industrial cogeneration, used to generate electricity, and used to heat and cool residential and commercial properties.

The U.S. EPA predicts a substantial growth in MWC will occur over the next 10-20 years. Today 99 MWCs nationwide incinerate about 4% of the annual volume of MSW, whereas it is conceivable that by the year 2000 one-third of the MSW will be incinerated in >300 MWCs. There is a definite trend moving toward incineration of MSW, and away from exclusively landfilling the waste.

The U.S. EPA has a limited opportunity to prospectively evaluate the potential environmental and health impact that may result from a sudden proliferation of municipal waste combustion. In this regard the agency has developed a methodology for the evaluation of emissions of pollutants into the atmosphere from the stacks of MWCs during incineration. The methodology consists of a series of environmental fate and transport models that utilize the known physical and chemical properties of specific pollutants to predict the atmospheric dispersion from stack emissions, the potential for surface deposition and accumulation; the movement of the settled pollutants through and into various environmental media; the potential bioaccumulation of pollutants into trophic systems; the potential for adverse effects on the vitality of natural ecosystems; and the potential for adverse effects on human health. With regard to evaluating potential human health effects, the methodology will estimate health risks resulting from inhalation of predicted ambient air concentrations of pollutants; ingestion of pollutants deposited on the ground an bioaccumulated into the food chain; ingestion of potable water or aquatic organisms contaminated by the surface runoff and the leaching and percolation of settled pollutants into water supplies; and ingestion of soil particles contaminated by deposited incinerator emissions.

The utility of the present methodology is limited by a number of gaps in the available technical data and significant uncertainties in many of the major analytical parameters. There is little question that the methodology can be improved by further research. One major limitation is that the methodology focuses only on pollutants emitted from the stacks of MWCs. Ideally the total pollutant loading resulting from the incineration process should be evaluated,

e.g., ash residues, aqueous residues, and stack emissions. The evaluation of stack emissions is further limited by the relatively small number of organic and inorganic pollutants that have been measured in MWC emissions. A final constraint on the methodology is the limited amount of data regarding the physical and chemical behavior of specific pollutants in the natural environment, and the adverse impact these pollutants may have on human health.

In the evaluation of the potential environmental impact of combustion sources, the U.S. EPA has traditionally focused on air emissions from the source, and on the human health risks from direct inhalation of predicted ambient air concentrations of pollutants. The present methodology represents an expansion of the analytical scope to include consideration of multiple pollutants, multiple exposure pathways, carcinogenic and noncarcinogenic risks posed to humans, and potential adverse effects to the natural environment.

Human exposure to incinerator emissions results from direct inhalation of ambient air concentrations of the pollutants and indirectly from skin contact of the pollutants, and ingestion of contaminated soil particles, water and food. Detailed experimental evaluation of the environmental fate and transport of MWC emissions have not been conducted under actual conditions. Therefore, mathematical models of fate and transport are currently the most feasible alternative to the assessment of exposure to MWC emissions. In addition to estimating concentrations that will be inhaled, these models can also be used to estimate the potential accumulation in soils of pollutants adverse to the promotion of human, animal and plant life, and accumulation of pollutants into the human and ecological food chain. The models specifically used in this analysis of MWC emissions are: the Human Exposure Model (HEM), the Industrial Source Complex Short-Term Air Dispersion Model; the Terrestrial Food Chain Model, the Surface Runoff Model, the Groundwater Contaminant Model, and the Dermal Exposure Model.

Given the complexities of predicting the environmental fate and transport of specific chemicals emitted, as well as predicting multiple routes of human exposure to specific chemicals, it is not currently feasible nor practical to apply the models to every existing or planned MWC. Therefore, the methodology employs a simplified modeling approach by using a hypothetical plant (in

western Florida) to characterize the potential adverse impacts of emissions from technologies typical of MWCs currently being planned or considered, and the Hampton, Virginia MWC to represent a reasonable worst case of the potential adverse impacts on air pollutant emissions from existing MWC technology.

The Industrial Source Complex Model (ISC)

The industrial source complex model is used to predict the dispersion of smokestack emissions from the hypothetical plant and the Hampton facility through the atmosphere, as well as to predict both wet and dry deposition of pollutants onto the surface. Assessments of potential risk from air emissions have primarily been concerned with health risks resulting from direct inhalation of ambient air concentrations of pollutants. The ISC assists in extending the risk evaluation to a consideration of their routes of population exposure to environmental pollutants and allows the U.S. EPA to predict the rate of deposition, over time, of pollutants believed to be adsorbed onto particulate matter in the smokestack exhaust gas, and attempt to calculate the spatial and temporal accumulation of these pollutants on the soil, surface water, groundwater and terrestrial food chain.

For purposes of exposure analysis from MWC emissions, the ISC Short-Term (ISCST) model program is utilized. The program makes mathematical calculations of dispersion and dry deposition and produces a printout of these values. However, the ISCST model as originally developed had no provision for calculating wet deposition of the emissions. Because this deposition pathway is considered to be of potential significance, the present methodology included an algorithm to estimate the effect of precipitation events on the rate of surface deposition.

Human Exposure Model (HEM)

The ISCST output is a concentration array for a total of 160 receptors, or 10 receptors along each of 16 wind directions, specified in concentric radial distances from each facility of 0.2, 0.5, 1, 2, 5, 10, 20, 30, 40 and 50 kilometers computed every 22.5° on a radius-polar grid pattern. This output is a suitable format for utilization with HEM. HEM is a general model that has been routinely used with the EPA's air regulatory program to estimate the carcinogenic risk to the population exposed by inhalation to predicted ambient

air concentrations of specified pollutants. The HEM also is capable of air dispersion modeling, and is often used in nationwide analysis of source categories.

Terrestrial Food Chain Model (TFC)

Contaminants associated with emissions from MWC are subject to deposition on surfaces downwind form the MWC. The fallout may be deposited on soil and/or vegetation.

Humans in the vicinity of the MWC have the potential to ingest contaminated soil directly or consume vegetation and animal tissues containing the contaminants. The TFC model has separate components for examining each potential exposure pathway. These components describe methods for using empirical data on contaminant uptake by plant or animal tissues to estimate tissue concentrations, and for integrating these estimates to give a picture of potential human dietary exposure. Potential exposure of children resulting from soil ingestion ("pica") is also estimated.

Surface Runoff Model

Contaminants asscciated with particulates emitted by MWCs are subject to deposition on surfaces downwind from the MWC at rates determined by meteorology, terrain, and particle physics. This fallout is subsequently subject to dissolution and/or suspension on runoff after precipitation events. Runoff moves over the surface of the earth to a surface water body where it mixes with other waters. As a consequence, humans utilizing water from the surface water body or aquatic life living therein may be exposed to runoff transported contaminants.

The methodology is formulated in three successive tiers that begin with simple but very conservative estimates, and proceed to more detailed analyses if the first tiers predict unacceptable risks. Both acute events and chronic exposure are evaluated, using standard approaches to calculate runoff volume and associated runoff potential. The methodology was originally developed to evaluate impacts from the application of municipal waste-waters sludge to land.

Groundwater Infiltration Model

Contaminants associated with particulate emitted from MWCs are subject to deposition on surfaces downward from the facility. This fallout is subsequently subject to dissolution in rain or meltwater from precipitation events. The dissolved portion can follow one of two pathways: either move over the surface as runoff to a surface water body or infiltrate into the ground and recharge the groundwater. As a consequence, persons using the groundwater may be exposed to groundwater transported contaminants. Aquatic life inhibiting surface water bodies fed by the contaminated aquifer could be exposed as well.

The methodology derived to calculate risks from the groundwater pathway was originally developed to evaluate impacts from the landfilling of municipal sludge. As for surface runoff, this methodology is formulated in three successive tiers. Only chronic exposure is evaluated using standard approaches to calculate leachate generation and associated groundwaters transport in the unsaturated zone.

Dermal Exposure Model

The dermal exposure model refers to human skin contact with contaminants from emissions of MWC deposited on the soil. The tissue of dermal absorption of deposited contaminants is very complex. There is a fundamental lack of data for percutaneous absorption of chemicals in human skin from soil. Other factors important for estimation of human exposure to contaminants by the dermal route also have many uncertainties. The model described in this document is offered as a possible approach for the estimation of human exposure and risk associated with a dermal exposure, but it is recognized that in most, if not all cases, the available data will not provide a satisfactory basis for risk calculations. Systemic toxic thresholds or carcinogenic potencies of chemicals by a dermal route of exposure have not been delineated by the U.S. EPA at the present time.

Ecological Effects from MWC Emissions

Methods to assess risk to terrestrial organisms represent a follow-up to the Terrestrial Food Chain (TFC) model. Components for assessing effects of deposited pollutants on herbivores, soil biota, predators of soil biota, and

plants are included. Methods to assess risk to aquatic organisms and wildlife preying on aquatic organisms follow from the surface runoff and groundwater infiltration models. Surface water concentrations predicted by these models are used to predict adverse effects on aquatic organisms or wildlife.

Example Calculations

Two chemicals have been selected to provide example calculations of risk: benzo(a)pyrene [B(a)P] and cadmium (Cd). Both chemicals are used only as examples for each methodology. The examples are shown for the Human Exposure, Terrestrial Food Chain, Surface Runoff, Groundwater Infiltration and Dermal Exposure models. The purpose of the examples are to assist the reader in the functional operation of the calculations for each methodology.

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